STEREOSCOPIC PANORAMIC IMAGE CAPTURE DEVICE

Background of the Invention

Field of the Invention

The present invention relates in general to a panoramic image capture device and, more specifically, to a panoramic image capture device for producing a stereoscopic panoramic image.

Description of the Prior Art

Panoramic cameras are known in the art. Such cameras often use a single, rotatable camera. Although such devices are suitable for stationary images, such devices typically produce blurred or distorted images when used to capture non-stationary objects. It is also known in the art to utilize an image capture system having a plurality of image capture devices. In this manner, a plurality of images can be captured, substantially simultaneously, and stitched together using processes known in the art. Although such systems substantially eliminate the problem associated with capturing objects in motion, such systems do not provide means for producing a stereoscopic image.

It is also known in the art to use a "fish-eye" lens to capture a panoramic image. Such images, however, import a large amount of distortion into the resulting image, and capture images of relatively low quality. Accordingly, it would be desirable to produce a panoramic image of lower distortion and higher quality.

Typically, to capture a stereoscopic image, two imaging systems are positioned next to one another to capture a particular image. Unfortunately, this method cannot be extrapolated to producing a stereoscopic panoramic image, as one image capture device would necessarily fall into the field of view of the adjacent image capture device. It would be desirable, therefore, to

provide a panoramic image capture system which could be utilized to produce a stereoscopic pair of panoramic images for a stereoscopic display of a particular image.

Summary of the Invention

In an advantage provided by this invention, an image capture system produces a stereoscopic pair of panoramic images.

Advantageously, this invention provides an image capture system for producing a seamless panoramic image.

Advantageously, this invention provides an image capture system for producing a stereoscopic panoramic image in motion.

Advantageously, this invention provides a stereoscopic panoramic image of minimal distortion.

Advantageously, this invention provides an imaging system for full-motion, real time, panoramic stereoscopic imaging.

Advantageously, in a preferred example of this invention, an imaging system is provided comprising a first image capture device, a second image capture device, and a third image capture device. Means are also provided for combining at least a first portion of a first image captured using the first image capture device with a portion of a second image captured using the second image capture device to produce a first combined image. Means are also provided for combining at least a second portion of the first image with at least a portion of a third image captured using the third image capture device, to produce a second combined image.

In the preferred embodiment, a plurality of image capture devices are utilized to produce a plurality of images, a portion of each of which is combined with a portion of adjacent images

2

to produce a first combined panoramic image. Similarly, a second portion of each image is combined with separate portions of adjacent images to produce a second combined panoramic image. Preferably, the first combined panoramic image, and second combined panoramic image are displayed in a stereoscopic orientation to produce a stereoscopic panoramic image. The imaging system of the present invention may be utilized to capture a plurality of images, to produce a full-motion stereoscopic panoramic image.

Brief Description of the Drawings

The present invention will now be described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 illustrates a front elevation of the imaging system of the present invention;

Fig. 2 illustrates a graphic depiction of image capture regions of adjacent image capture devices of the imaging system of the present invention;

Fig. 3 illustrates a bottom perspective view of the final panoramic stereoscopic image displayed on a screen, and the polarized glasses used to view the image;

Figs. 4A-4B illustrate a left panoramic image and right panoramic image; and

Figs. 5A-5B illustrates images associated with first image buffer and second image buffer;

Figs. 6A-6C are a flowchart of the transformation process utilized in association with the imaging system of the present device, to transform the plurality of images captured with the imaging devices into a first panoramic image and a second panoramic image to produce a stereoscopic panoramic image; and

Fig. 7 illustrates a perspective view of a 360 degree unobstructed panoramic stereoscopic image, created using the camera of Fig. 1.

Detailed Description of the Preferred Embodiment

Referring to Fig. 1, a camera (10) is shown having a body (12) constructed of plastic or other similar lightweight material. In the preferred embodiment, the body (12) is substantially spherical, having a diameter preferably between .001 and 500 centimeters, and more preferably, between 10 and 50 centimeters. Provided substantially equally spaced across the surface of the body (12) are a plurality of lenses (14). The lenses (14) are preferably circular lenses having a diameter of preferably between 5 angstroms and 10 centimeters, and more preferably, between .5 and 5 centimeters. In the preferred embodiment, the lenses are model number BCL38C 3.8 millimeter micro lenses, manufactured by CBC America, located at 55 Mall Drive, Commack, NY 11725. As shown in Fig. 2, the lenses (14) are each associated with a charge coupled device (CCD) assembly (16), such as those well known in the art. Although in the preferred embodiment a GP-CX171/LM CCD color board camera, manufactured by Panasonic and available from Rock2000.com is used, any known image capture system may be used. As shown in Fig. 2, all of the CCD assemblies (16) are coupled to a central processing unit (CPU)(22). In the preferred embodiment, the CPU (22) is a 900 MHz, Pentium®4 class personal computer provided with an Oxygen GVX210 graphics card manufactured by 3Dlabs of 480 Pontrero, Sunnyvale, CA 94086. Although the CPU may be of any type known in the art, it is preferably capable of quad buffering and utilizing page flipping software in a manner such as that known in the art. The CPU (22) is coupled to a head mounted display (24) which, in the preferred

4

embodiment, is a VFX3D, manufactured by Interactive Imaging Systems, Inc., located at 2166

Brighton Henrietta Townline Road, Rochester, NY 14623.

As shown in Fig. 2, the lenses (14) are divergent from one another, and offset twenty

degrees from one another along the arcuate surface of the body (12). This divergency allows

each lens to have a substantially similar focal point. Each lens (14) has a fifty-three degree field

of view, which overlaps the field of view of a laterally adjoining lens by between ten and ninety

percent, and, preferably, between fifty and sixty-five percent. As shown in Fig. 2, a first image

capture unit (26) is associated with an optical axis (28), bisecting the image bordered on one side

by a left side plane (30) and on the other side by a right side plane (32). The lens (14) of the

image capture unit (26) is focused on a defined image plane (34), divided into a left image plane

(36) and a right image plane (38).

Similarly, a second image capture unit (40) is also provided with an optical axis (42), a

left side plane (44), a right side plane (46), a defined image plane (48), a left image plane (50),

and a right image plane (52). A third image capture unit (54), to the right of the first image

capture unit (26), is provided with optical axis (56), a left side plane (58), a right side plane (60),

a defined image plane (62), a left image plane (64), and a right image plane (66).

By providing a plurality of image capture units (26), (40) and (54), dividing the defined

image planes (34), (48) and (62) in halves, and orienting the image capture units (26), (40) and

(54) as shown in Fig. 2, every point associated with a final panoramic image is within the

defined image plane of at least two adjacent image capture units, (26), (40) or (54). As shown in

Fig. 5A-5B, the defined image planes of adjacent image capture units overlap vertically,

preferably about 1-20 percent, more preferably 5-10 percent, and 7 percent in the preferred

embodiment. Similarly, the defined image planes of adjacent image capture units overlap

horizontally, preferably about 20 percent, more preferably 5-10 percent, and 6 percent in the preferred embodiment. These overlaps aid in the "stitching" process described below.

To produce the final panoramic image (68) of the present invention, a first panoramic image (72) and second panoramic image (74) are created. (Figs. 3 and 4A-4B). To create the first panoramic image (72), an image (76), associated with the left image plane (36) of the first image capture unit (26) is combined with an image (78), associated with the left image plane (50) of the second image capture unit (40) and an image (80), associated with the left image plane (64) of the third image capture unit (54). (Figs. 2, 4A and 5A). As shown in Fig. 2, the associated image planes (36), (50) and (64), preferably overlap by .5-30 percent, more preferably by 10-20 percent, and 13 percent in the preferred embodiment, but are not parallel to one another, and are not tangent to a curve defining the first panoramic image (72). (Fig. 2 and 4A). Accordingly, the images (76), (78), (80), (82), (84) and (86), associated with planes (36), (50) and (64) must be transformed, to remove distortion associated with their non-parallel orientation, before they can be stitched together as described below to form the final panoramic image (68). (Figs. 2, 3, 4A-4B and 5A-5B).

Once the images (76), (78) and (80), associated with the left image planes (38), (52), (66), and the images (82), (84) and (86), associated with the right image planes (36), (50) and (64) have been collected from all of the image capture units (26), (40) and (54), the images are transmitted via hardwired, wireless, or any desired connection to the CPU (22). The CPU (22) then transforms the images in accordance with the process described in Figs. 6A-6C. (Figs. 2, 4A and 5A). As shown in step (88), source images, which in the preferred embodiment are rectilinear images, but which may, of course, be any type of image, are obtained from the image

6

capture units (26), (40) and (54). (Figs. 2, 4A, 4B and 6). As shown in step (94), the CPU (22) defines registration pixel pairs for the untransformed source images.

Thereafter, as shown in step (96), the CPU(22) creates an input file. The input file includes the height and width of the final panoramic image (68), the source information, and registration point information. The source information includes the file name and path of the source image, the height and width of the source image in pixels, and the yaw, pitch and roll angles of the source of the associated image capture unit. The horizontal field of view of the image capture unit, which is preferably between 1 and 80 degrees, more preferably between 30 and 60 degrees, and 53 degrees in the preferred embodiment, is defined by the left side plane and right side plane, the X Shift, Y Shift and zoom values of the source image. The information associated with the registration points includes information regarding the source image associated with the first-pixel position of the registration point, a horizontal and vertical pixel position in the first source image, list index of information regarding the source image associated with the second pixel position, and a horizontal and vertical pixel position in the second source image.

The images (76-86) associated with the image planes (36, 38, 50, 52, 64 and 66) are rectilinear, normal flat-field images, and the panoramic images (72 and 74) are equirectangular, representing pixel mapping on a spherical surface in a manner such as that shown in Figs. 4A-4B. Accordingly, once the CPU (22) creates the input file, as shown in step (98), the registration pixel pairs must be transformed to locate their position in the final panoramic image (68).

Starting with an arbitrary source image, a vector is defined that represents a first pixel of a given registration pixel pair in three-dimensional space, locating it on the final

panoramic image (68). This is accomplished by applying the following matrix

transformation to each pixel:

Define segment x: Alter the horizontal position of the pixel in the source image so that it is relative to the image's center. Then compensate for the xShift and zoom variables of the source image.

Define segment y: Alter the vertical position of the pixel in a similar way.

Define segment z: Using various source image variables, determine the z segment that corresponds to the scale provided by the image's size in pixels.

Transform the vector so that it corresponds to the rotation angles of the source camera. This is calculated by transforming the vector by each of three rotational matrices:

- Rotation about x-axis:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(pitch) & \sin(pitch) & 0 \\ 0 & -\sin(pitch) & \cos(pitch) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

- Rotation about y-axis:

$$\begin{pmatrix} \cos(yaw) & 0 & -\sin(yaw) & 0 \\ 0 & 1 & 0 & 0 \\ \sin(yaw) & 0 & \cos(yaw) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

- Rotation about z-axis:

$$\begin{pmatrix} \cos(roll) & \sin(roll) & 0 & 0 \\ -\sin(roll) & \cos(roll) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Upon matrix transformation, the pixel vector represents the global globX, globY, and globZ

positions of that point in three-dimensional space. The CPU (22) then converts these positions

into spherical coordinates and applies them directly to the final panoramic coordinates. The

8

vector's yaw angle represents its horizontal panorama position, newX, and its pitch angle represents its vertical panorama position, newY.

As shown in step (100), once the registration pixel pairs have been mapped to the final panoramic image (68) in this manner, the CPU (22) calculates the distance between the registration pixel pairs. If the average distance of the registration pixel pairs for a given source image are not yet minimized, as would be the case upon the initial transformation, shown in step (102), the yaw of the source image is altered slightly, whereafter the process returns to step (98) and the registration pixel pairs are again transformed to pixel points in the final panoramic image (68). This process continues, altering the yaw, until the average distance of the source image registration pixel pairs is minimized. Thereafter, the pitch, roll, X Shift, Y Shift and zoom are altered, until the average distance of the associated registration pixel pairs is minimized. Once the yaw, pitch, roll, X Shift, Y Shift and zoom of a particular source image is optimized, as shown in step (104), the transformation procedure is repeated for all source images until they are all thus optimized.

As shown in step (106), once all of the source images have been thus optimized, the average distance of all source image registration pixel pairs is calculated and, if they are not yet minimized, the yaw, pitch, roll, XShift, YShift and zoom of the source images are altered as shown in step (108), and the process returns to step (98), where the process continues, until the distance between the registration pixel pairs is minimized across all of the source images.

Once the average distance between the registration pixel pairs has been minimized across all source images, as shown in step (110), an output file is created, identifying the height and width of the first panoramic image (72), the yaw, pitch, roll, XShift, YShift and zoom transformation image information relative to each particular source image. Thereafter, as shown

9

in step (112), for each pixel within a given source image, a vector is defined representing the particular pixel's position in three dimensional space, using the vector transformation described above.

Once a vector has been defined, as shown in step (114), the vector is transformed to reflect the yaw, pitch, roll, XShift, YShift and zoom information associated with the source image as defined in the output file. After completion of the transformation of the vector, as shown in step (116), the transformed vector is associated with a pixel in the final panoramic image (68). As shown in step (118), this process is repeated until all of the pixels in a particular source image have been transformed into vectors, and their position located on the final panoramic image (68)

As shown in step (120), once all of the pixels of a given source image have been located on the final panoramic image (68), two image buffers (90) and (92) are created, each having a height and width equal to that of the final panoramic image (68). (Figs. 3, 5A-5B and 6B). As shown in step (122), once the image buffers (90) and (92) have been created, vector transformation information associated with a quadrilateral of four adjacent pixels of a particular source image is utilized to draw the quadrilateral of pixels onto the appropriate image buffer (90) or (92). (Figs. 5A-5B and 6C). If the pixel is in the left image planes (38), (52) or (66), the pixel is written to the left image buffer (90). If the pixel is in the right image planes (36), (50) or (64), the pixel is in the right image buffer (92). (Figs. 2 and 5A-5B).

As shown in step (124), since the transformation is likely to spread out the quadrilateral of pixels on the image buffer, there will likely be gaps between pixels as they are converted from their rectilinear location to their equirectangular location in the associated image buffer (90) or (92). (Figs. 5A-5B and 6C). When the quadrilateral of pixels is located on the associated image

buffer (90) or (92), the gaps thereby created are filled as smoothly as possible, using a linear

gradient of the corner pixel colors, in a manner such as that known in the art. Known linear

gradient fill techniques are also used to diminish visible seams between images. As additional

source image information is applied to the image buffers (90) and (92), for areas of the image

buffers (90) and (92) that have already been filled with pixel data, the alpha transparency of the

new overlapping pixels is linearly degraded, smoothing the resulting seam as described below.

Accordingly, when mapping the quadrilateral to the associated image buffer (90) or (92),

the central processing unit (22) eliminates the gaps by interpolating the internal pixel values,

using any method known in the art, which may include comparing the gap to the adjacent pixels,

or "white boxing" the gap by utilizing the immediately preceding frame and immediately

succeeding frame in a motion capture system, to extrapolate the most appropriate pixel value for

the gap. As shown in step (126), steps (122) and (124) are repeated until all of the source image

pixels have been mapped to the appropriate image buffer (90) or (92).

Once all of the pixels have been mapped, as shown in step (128), the first image buffer

pixels are compared to the first panoramic image pixels. If the first panoramic image (72) does

not have a pixel associated with a pixel in the first image buffer (90), the CPU (22) sets the pixel

in the first image buffer (90) to maximum visibility. If the first panoramic image (72) already

has a pixel associated with a pixel in the first image buffer (90), the existing pixel is compared to

the corresponding pixel in the first image buffer (90). If the pixel in the first image buffer (90)

has a shorter distance to the center of its respective source image than does the existing pixel, the

pixel in the first image buffer (90) is set to maximum visibility. Conversely, if the pixel in the

first image buffer (90) has a greater distance to the center of its respective source image than that

of the existing pixel, then the pixel in the first image buffer (90) is set to minimum visibility.

11

The process is repeated to merge pixels of the second image buffer (92) into the second

panoramic image (74).

As shown in step (130), the overlapping edges of the image in the image buffers (90) and

(92) are feathered by degrading visibility of the pixels over the area of overlap. This feathering

smoothes the overlapping areas of the image once it is merged from the image buffers (90) and

(92) into the panoramic images (72) and (74). As shown in step (132), once the image buffer

pixels have been set to the appropriate visibility, and the image of the image buffers feathered,

the images in the image buffers are merged into the first and second panoramic images (72) and

(74). As shown in step (134), steps (122) through (132) are repeated until all of the source

images have been merged into the first and second panoramic images (72) and (74). As noted

above, the images (76), (78) and (80) associated with the left image planes (36), (50) and (64) of

the image capture units (26), (40) and (54) are used to create the first panoramic image (72), and

the images (82), (84) and (86) associated with the right image planes (38), (52) and (66) of the

image capture units (26), (40) and (54) are used to create the second panoramic image (74).

Once both of the final panoramic images (72) and (74) have been created, as shown in

step (138), the panoramic images (72) and (74) are displayed together as the final panoramic

image (68). (Figs. 3, 4A and 4B). The panoramic images (72) and (74) may be reverse polarized,

shown on a standard panoramic screen (140), such as that shown in Fig. 4, and viewed using

glasses (142) having lenses of reversed polarity. Alternatively, the panoramic images (72) and

(74) may be conveyed digitally to the head mounted display (24) shown in Fig. 1. The CPU (22)

can send multiple panoramic images to the head mounted display (24) using known "page-

flipping" techniques to send and separately display the images in the left and right displays of the

head mounted display (24), as appropriate. This process can be used to animate the display as a

full 24 frame per second motion picture, or to display multiple visual images to each display. The head mounted display unit (24) may also be provided with an orientation sensor (144), such as those well known in the art, to change the image provided to the head mounted display (24) as the imaging unit moves. In this manner, a user (not shown) may look up, down, and in either direction, to see that portion of the final panoramic image (68) associated with the vector of the user's line of sight. In this manner, the user will have the feeling of actually looking around a three-dimensional space.

In an alternative embodiment of the present invention, the camera may be provided with a plurality of image capture pairs having rectilinear capture systems oriented substantially parallel to one another. The pairs are offset by a predetermined factor to obtain a desired stereoscopic image. Because the images are captured in pairs, the transformation process associated with this embodiment is identical to that described above, albeit instead of dividing the images in half, and sending pixels from each half to a separate image buffer, all of the pixels associated with the images from the "left" image capture devices of each image capture device pair are sent to one image buffer, and all of the pixels associated with images from the "right" image capture devices are sent to another image buffer.

In another alternative embodiment of the present invention, the camera (10) and CPU (22) may be utilized to capture twenty-four or more frames per second, and display the final panoramic image (68), in real time, as a motion picture.

In yet another alternative embodiment of the present invention, computer generated graphical information, produced in a manner such as that well known in the art, may be combined with the final panoramic images (72) and (74) in the central processing unit (22) to provide a seamless integration of actual images captured with the camera (10), and virtual reality

images (146). (Fig. 3) This combination produces a seamless display of real and virtual panoramic stereographic virtual images.

In yet another alternative embodiment of the present invention, the images captured by the camera (10) may be transformed, utilizing the above transformation procedures, to produce a seamless 360-degree panoramic monographic image. As shown in Fig. 1, the camera (10) is provided with a support post (148) and a transportation unit such as a remote control carriage (150) used in association with remote control cars and the like. Images associated with the left image planes of the image capture units may be used to produce a combined image and the images associated with the right image planes of the image capture units may be used to overwrite and fill the combined image to hide the support post (148), carriage (150) and any other camera equipment otherwise visible in the combined image. The foregoing transformation procedures may be utilized for such overwriting and filling. In this manner, only those images which do not include the undesired information are mapped to a final panoramic image (152), which may be displayed on a spherical screen (154) or on the head mounted display (24). (Figs. 1 and 7). For that portion of the image reflecting the area covered by the footprint of the carriage (150), the interpolation and feathering procedures detailed above may be utilized to approximate the image lying beneath the carriage (150), to produce the appearance of a completely unobstructed 360-degree image.

Although the invention has been described with respect to the preferred embodiment thereof, it is to be also understood that it is not to be so limited, since changes and modifications can be made therein which are within the full intended scope of this invention as defined by the appended claims.